

Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment: Number 198

Nanoengineering of Surfaces : Solvent-Less vapor deposition Followed by In-situ Polymerization (SLIP)

Kevin C. O'Brien¹, Steve Letts², Chris Spadaccini², Dave Sanders², Jeff
Morse², Steve Buckley², Larry Fischer²

¹SRI International

²Lawrence Livermore National Laboratory

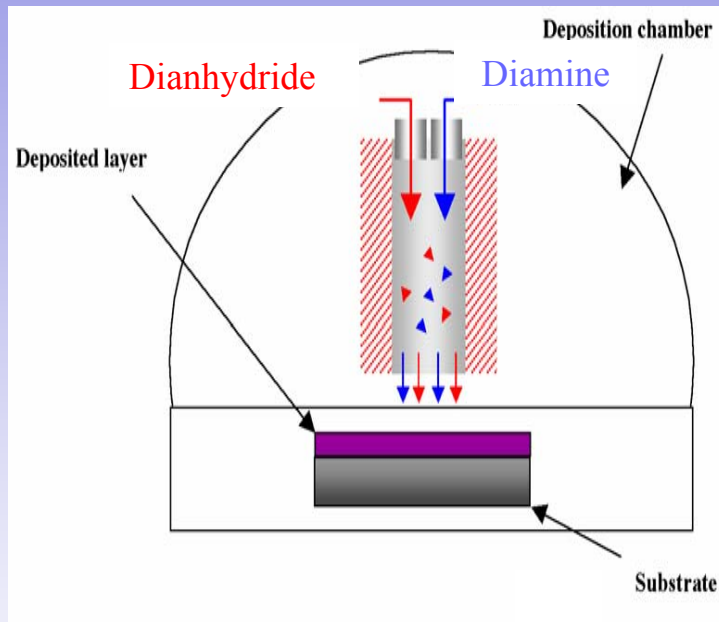
May 8-11, 2006 • Hilton Alexandria Mark Center • Alexandria, Virginia

Overview

- ***Capture Need***
 - High Selectivity coupled with high mass transfer rates to achieve process economics
 - Commonly a tradeoff between these two features
- ***Benefits of Nanoengineered Films***
 - Uniform Nanometer scale films combine high selectivity with high mass transfer rates, thereby improving process economics.
- ***Features of SLIP Process***
 - Robust
 - Scalable for high volume production
 - Designed for High Performance Materials

SLIP: An Enabling Technology

SLIP: Solvent-Less vapor deposition followed by In situ Polymerization



- **Solvent-less process for deposition of high performance polymeric films**
- **To Date: Deposited films range in thickness from 50 nm to 120 μm**
- **Monomers deposited in the vapor phase onto substrate**
- **Substrate remains at room temperature**

A Variety of Materials can be deposited using the SLIP process

- **SLIP was designed for condensation polymers, e.g. polyimides, nylons, polybenzimidazoles, polybenzoxazoles, etc**
- **Provides a means to deposit high temperature and high performance polymeric coatings**
- **Many of these materials are traditionally deposited using a solvent**
- **Other methods are unable to deposit layers of materials at nano-levels with high uniformity in thickness**

SLIP has been used to Coat a Variety of Substrates

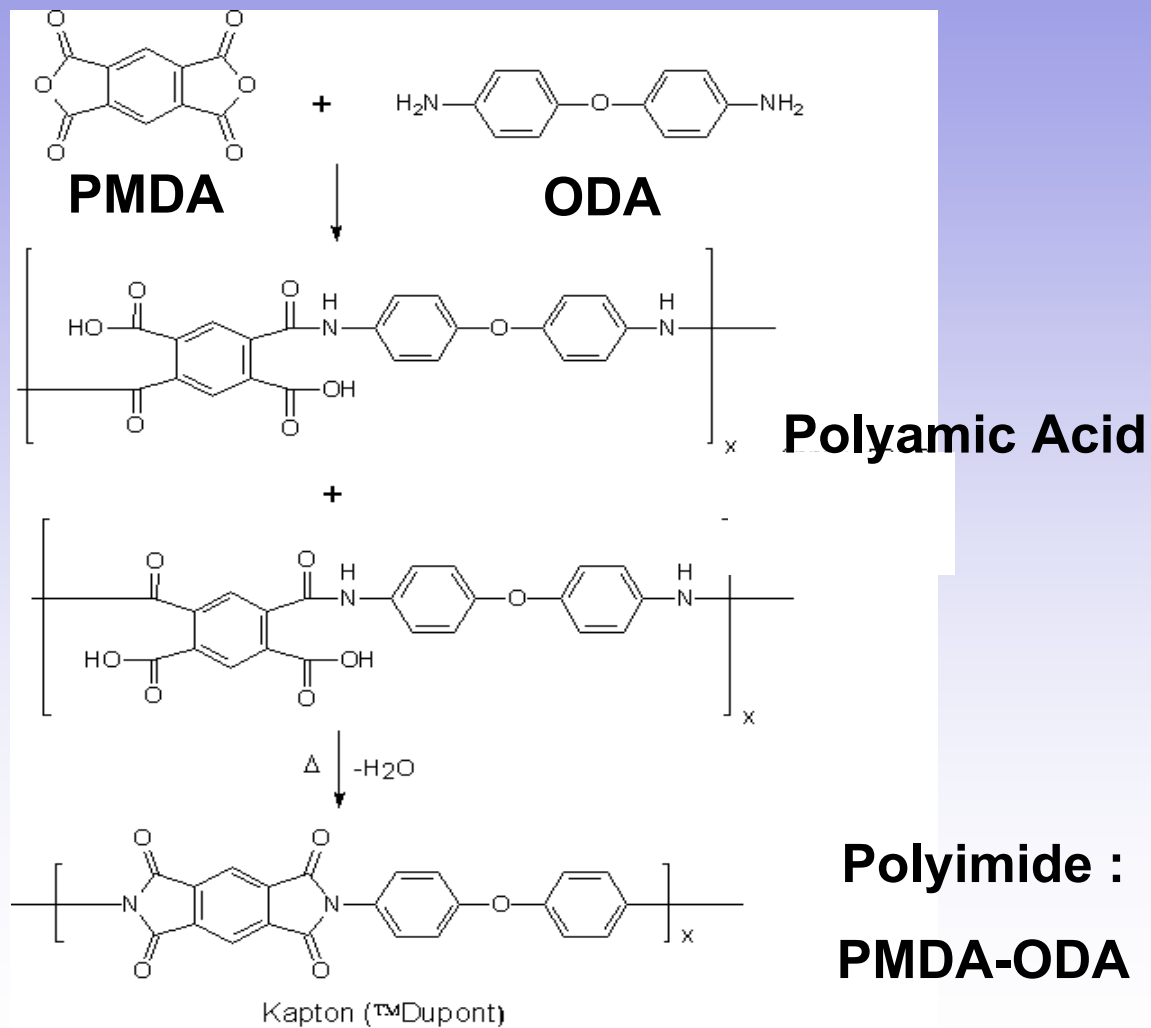
- **Sampling of substrates used:**
 - **Polymers:**
 - Polycarbonate, Teflon AF, nylon, silicone, plasma polymer
 - **Inorganics:**
 - Silicon wafers, glass
- **Some substrates were coated in both a flat sheet, fiber, and spherical (particle) form**
- **Excellent adhesion was observed**

Traditional Polyimide Synthesis

Typically run in
solvent such
as NMP

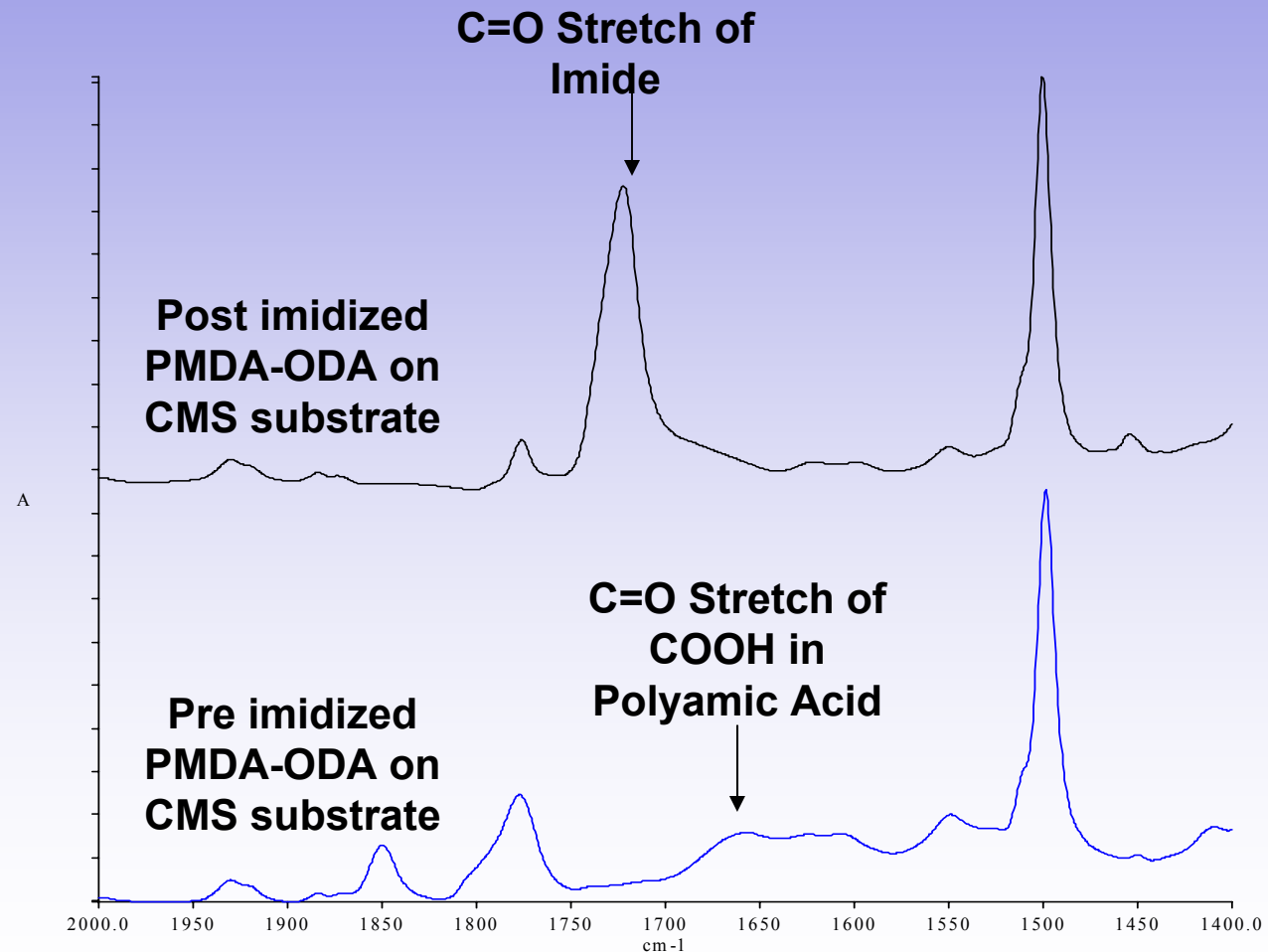
Imidize at 350°C

Issue is residual
solvent in final
film

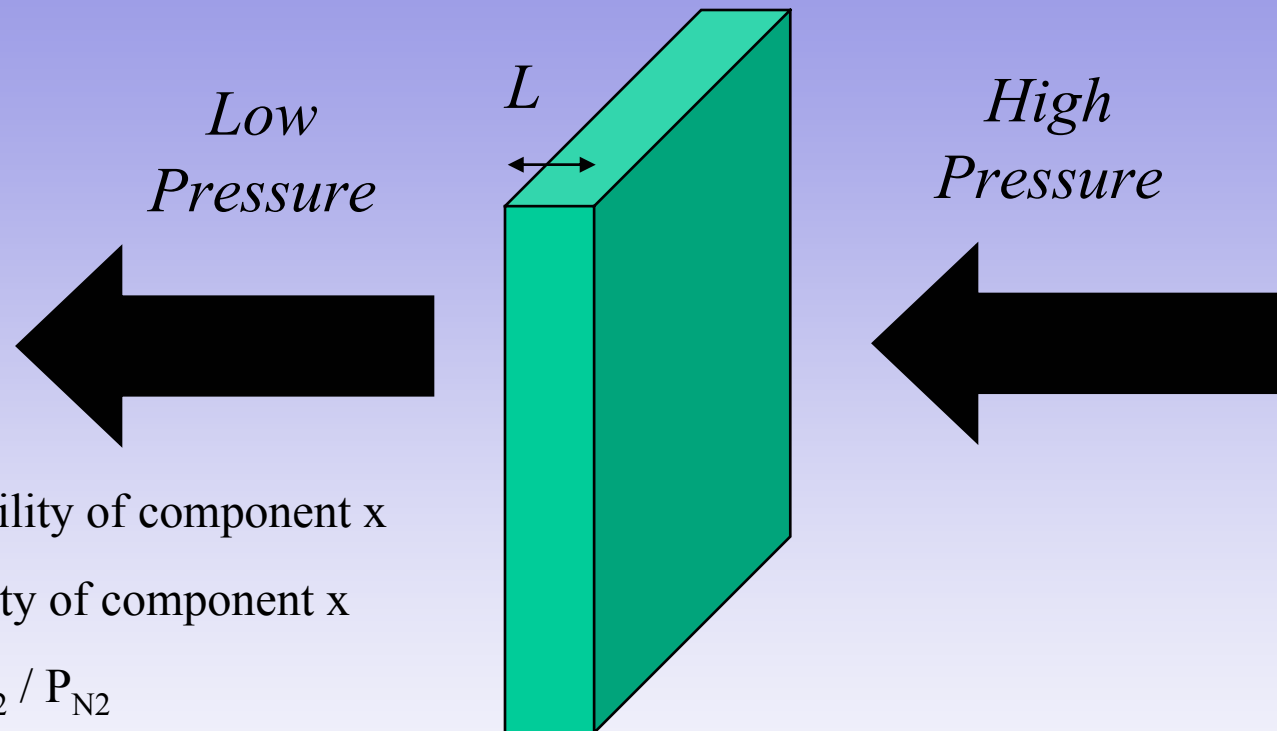


SLIP Enables Imidization at Lower Temperatures than Conventional Processing

Same amount of Imidization accomplished at 180°C with SLIP as obtained with conventional processing at 350°C



Gas Transport in Membranes



P_x = Permeability of component x

α_x = selectivity of component x

$\alpha_{\text{CO}_2/\text{N}_2} = P_{\text{CO}_2} / P_{\text{N}_2}$

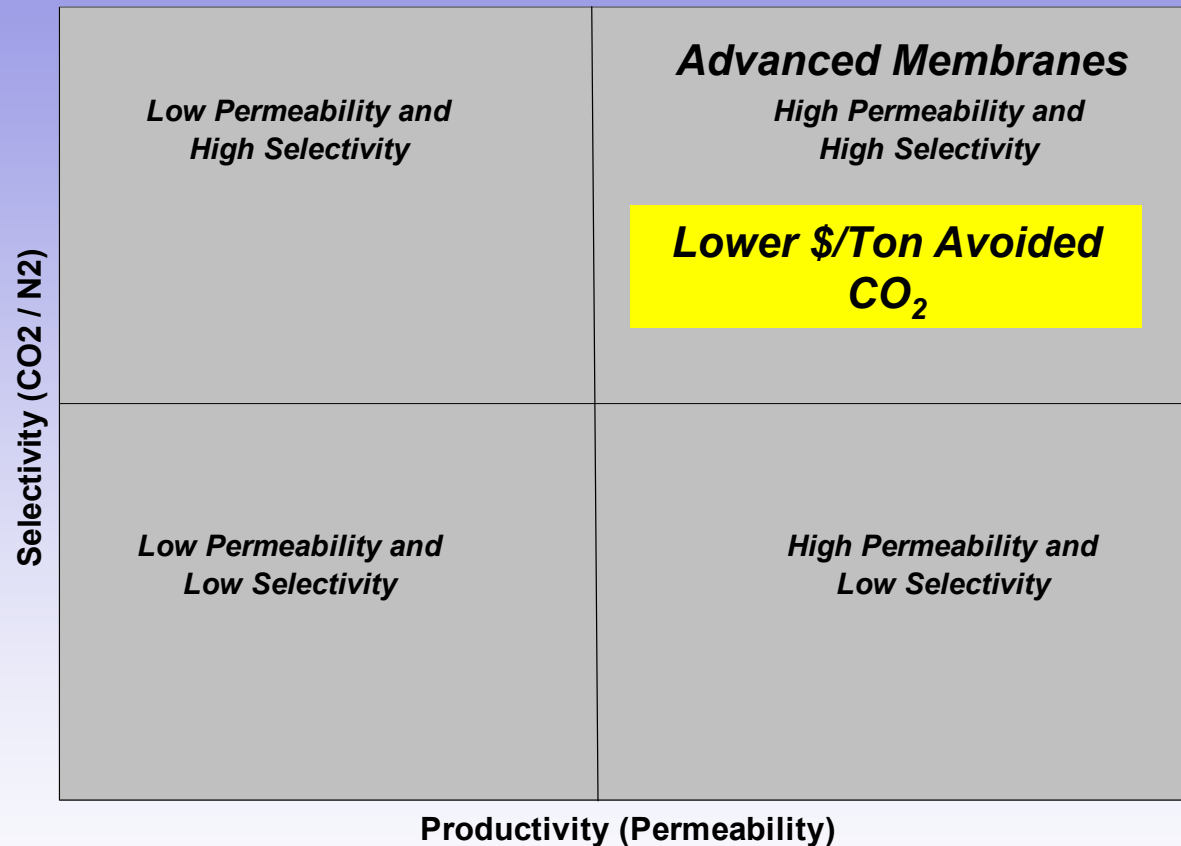
L = thickness of discriminating layer

P_x = permeance of component x

$P_x = P_x / L$

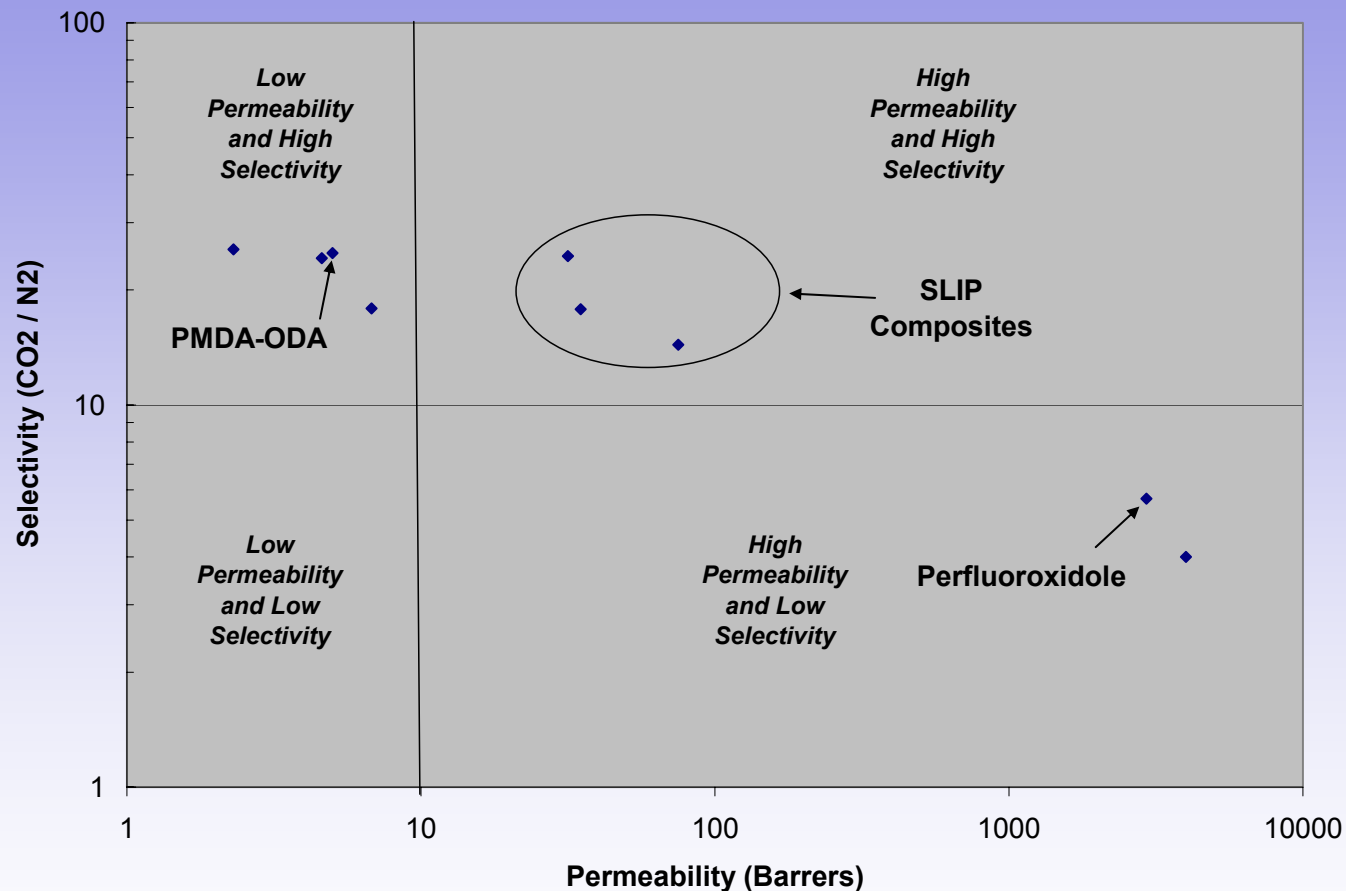
Target is large $\alpha_{\text{CO}_2/\text{N}_2}$ **AND** P_{CO_2}

Overcoming Lower Selectivity / Permeability is Key to Improving Capture Economics



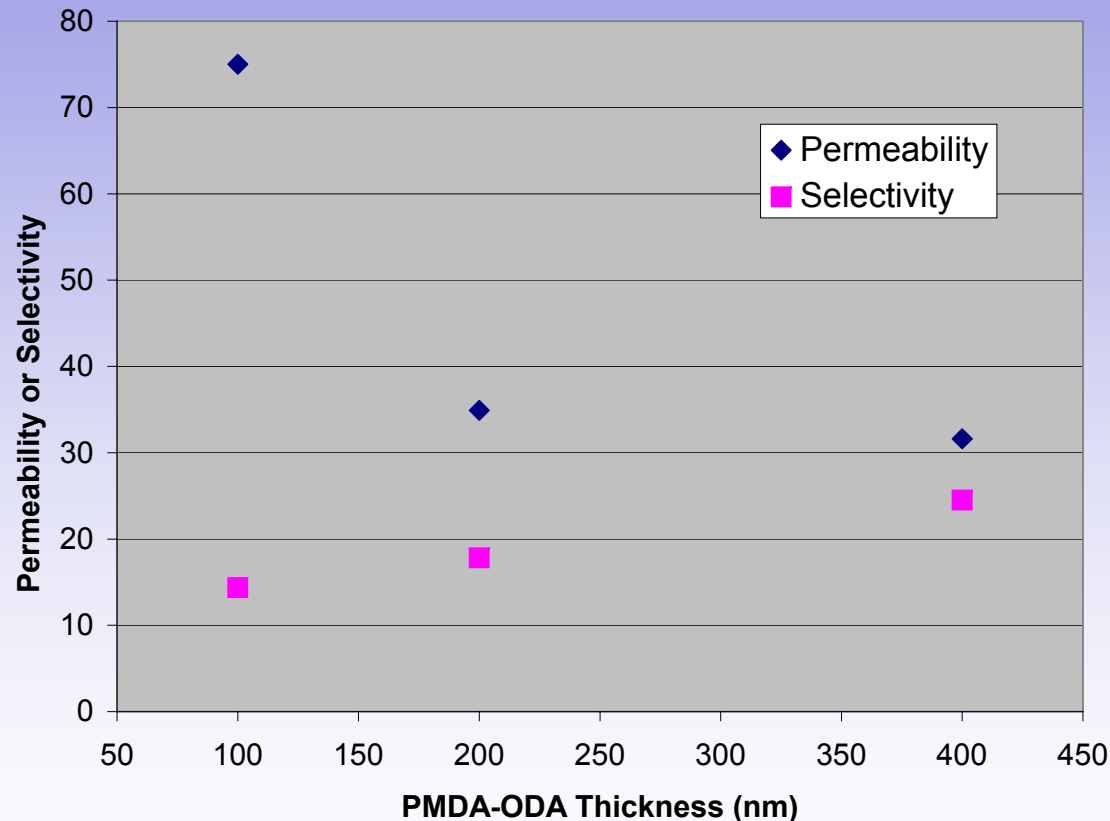
- Current membranes exhibit lower Permeability and Selectivity
- Advanced membranes increase permeability with a significant increase in selectivity which lowers \$ / Ton avoided Carbon

Phase I Study Funded by DOE Indicates SLIP Enhances Performance of Materials



- **SLIP coatings have 6 to 15 times greater permeability than conventionally fabricated PMDA-ODA materials**

SLIP Coatings in the 100 to 400 nm Range Exhibit Desirable Permeability and Selectivity Combinations



- **CO₂ Permeability (Barrers) and CO₂ / N₂ Selectivity of composite controlled by thickness of polyimide layer (PMDA-ODA)**
- **Coating thickness of 100 to 400 nm per side results in excellent permeability and selectivity combination**

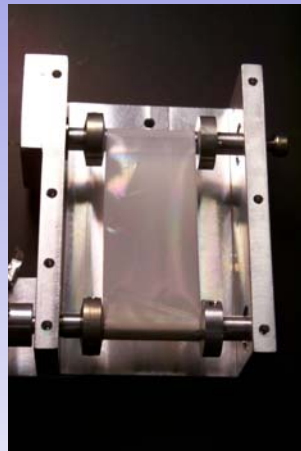
SLIP Offers Many Advantages over Conventional Membrane Fabrication

	Conventional Membrane Fabrication	SLIP
Produces hollow fibers or flat sheets	YES	YES
Requires solvents to Fabricate	YES	NO
Need to Handle Contaminated Water	YES	NO
Directly applies monomers	NO	YES
Highly uniform discriminating layer	NO	YES

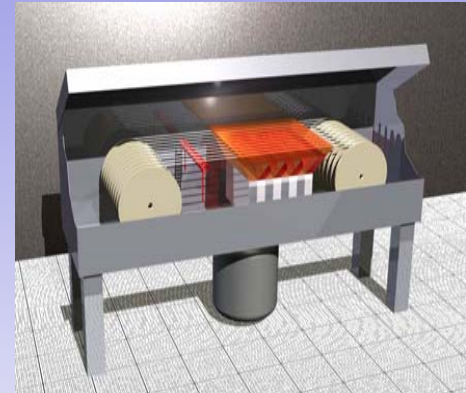
Roadmap to Scale-up of SLIP Coater



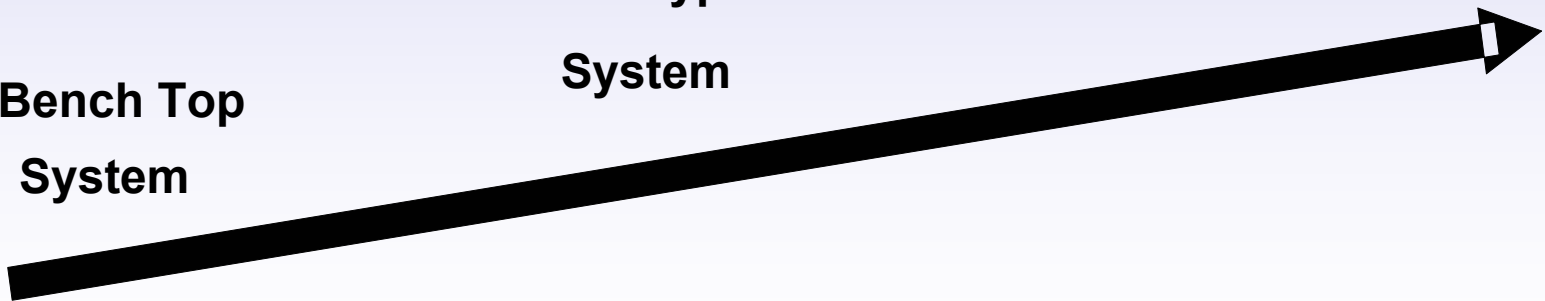
**Bench Top
System**



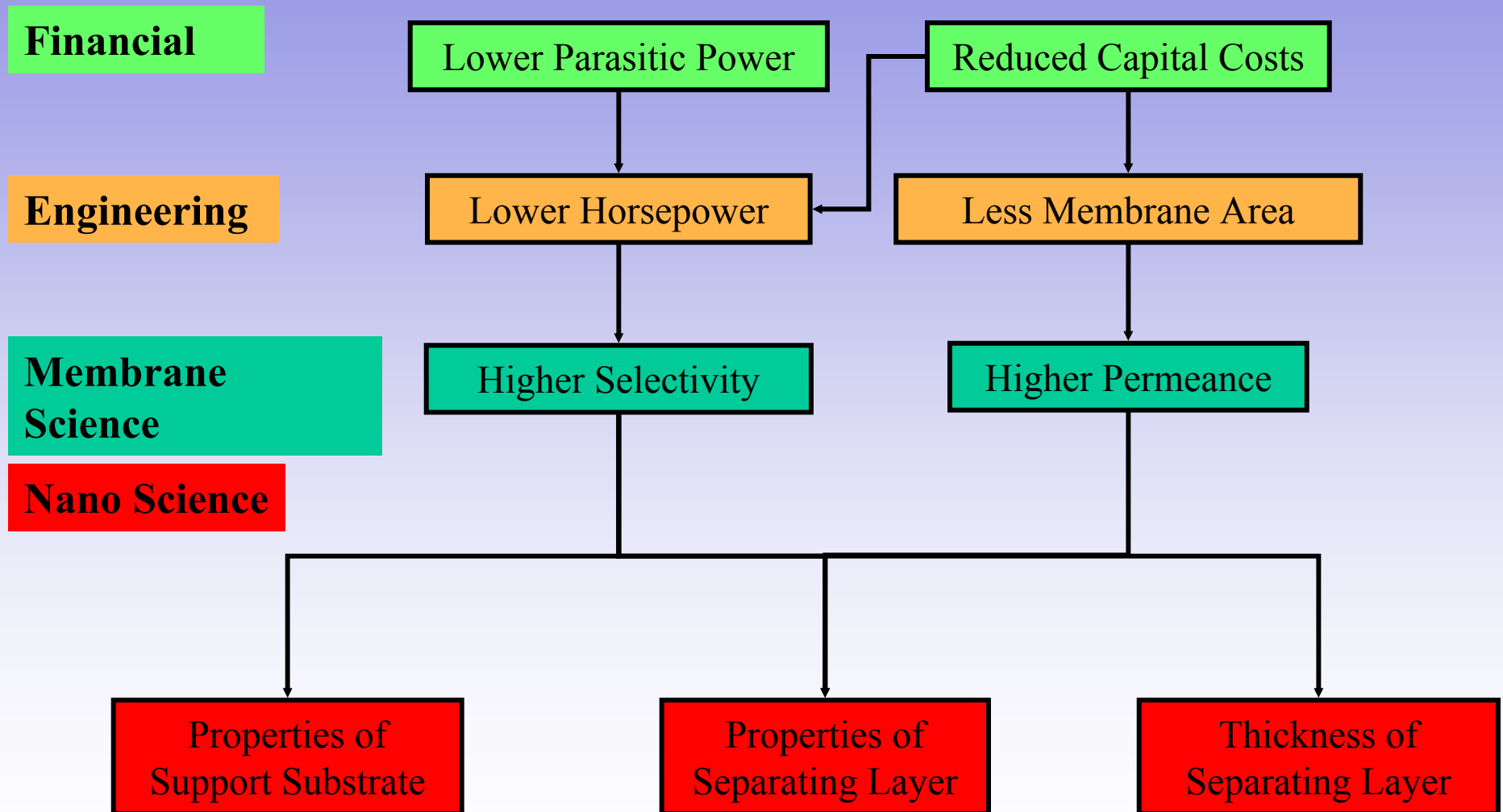
**Prototype
System**



**Construct
Pilot System**

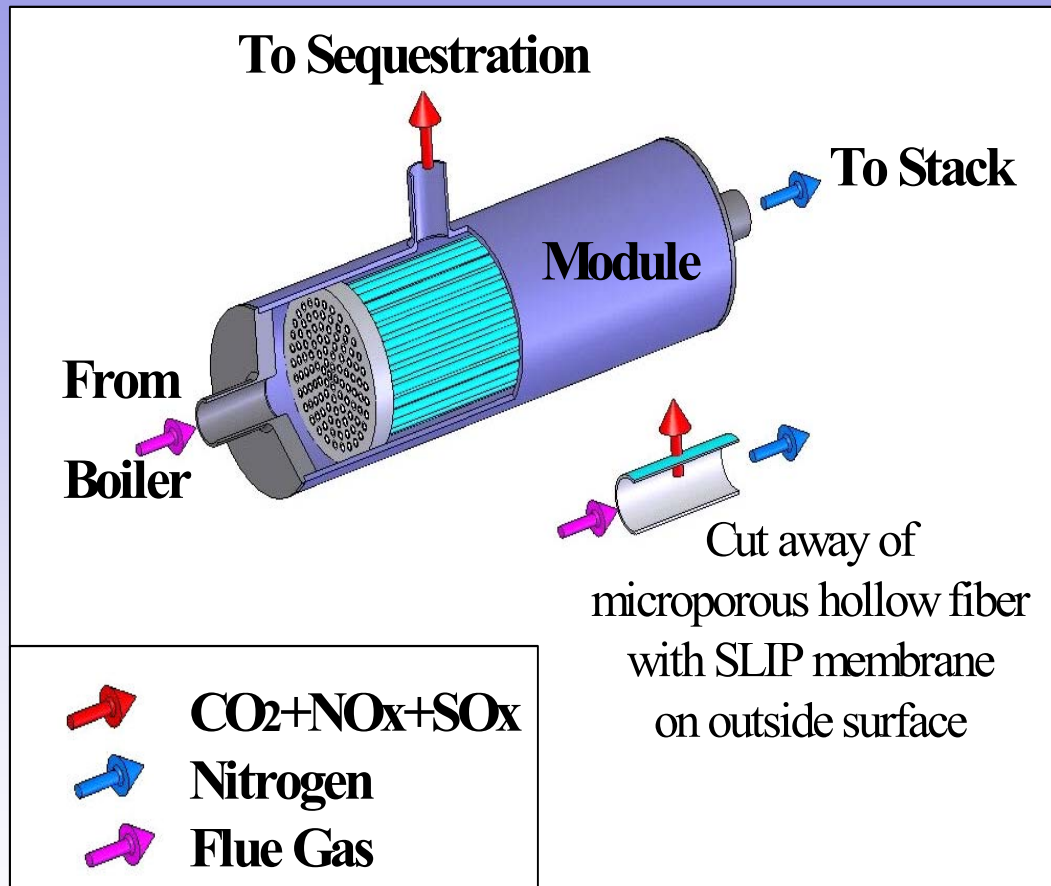


Designing at the Nano Scale to Achieve Financial Targets at the Mega Scale



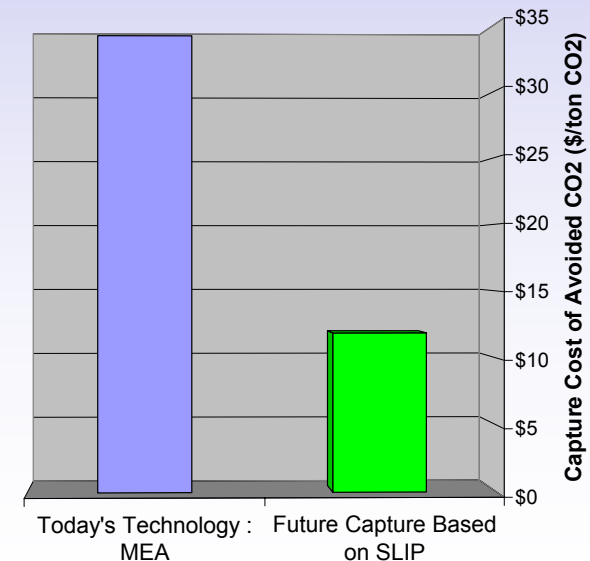
Advanced Gas Separation Membranes

Lower Cost of Carbon Capture



Schematic of working membrane module

Target Cost expected to be 65% lower than conventional amine-based technologies



Summary

- **SLIP enables the deposition of high performance polymer coatings on a variety of materials**
- **Data demonstrates that SLIP films can separate components of interest**
- **The SLIP coating process is scaleable and manufacturable**
- **Nanoengineered SLIP films could impact both pre- and post- combustion capture approaches**